VIEWPOINT:
GETTING BURNT BY WEAPONS PLUTONIUM: SECURITY IMPLICATIONS OF U.S. DISPOSITION OPTIONS

by Adam Bernstein

The use of plutonium as fuel in civil reactors is a major threat to global security. It requires processing tons of the material in a bulk form difficult to protect from theft—yet only a few kilograms suffice to make a Hiroshima-sized bomb. In addition, plants and materials in civil plutonium fuel cycles can be quickly diverted to weapons production. These risks, already substantial, will increase as Japan, Britain, France, India, and Russia proceed with plans to separate and store ever-larger amounts of weapons-usable plutonium.[1] Finally, there is the risk of proliferation by example: civil use of plutonium in one country can serve as encouragement or excuse for its use in other countries, just as its military use has helped stimulate nuclear weapons proliferation.

Recognizing these dangers, the United States—alone among the nuclear weapons states—had until recently maintained a policy of not separating plutonium from spent reactor fuel and had sought to discourage plutonium use worldwide.[2] But in December 1996, Energy Secretary Hazel O'Leary and the Clinton administration announced a two-year test program to determine the feasibility of irradiating military plutonium surpluses in U.S. civil reactors. If it proceeds with the program, the administration will undermine past U.S. nonproliferation policy by providing strong political and economic stimuli for the use of plutonium in commercial reactors at home and abroad.

The U.S. Department of Energy (DOE) is about to undertake a 25 to 30 year plutonium disposition campaign. The goal of the campaign is to put the United States' vast surpluses of military plutonium into a physical form that is difficult to steal or to reuse quickly in weapons. After reviewing a wide range of technologies for this purpose, the DOE's December announcement narrowed the field to two.[3] Surplus plutonium stocks could be immobilized in glass or ceramic logs along with highly radioactive wastes, or they could be manufactured into a plutonium-based fuel for irradiation in civil reactors. Since some of the surpluses are definitely unsuitable for the fuel manufacturing process, this means that either immobilization will be used exclusively, or that both disposition technologies will be used.

This essay argues that the DOE should abandon the use of reactors for the disposition program and instead devote its resources to the development of plutonium immobilization methods. As discussed below, there are no compelling reasons to use reactors in the campaign, and their use would raise strong nonproliferation risks. Conversely, by pursuing disposition using immobilization methods alone, the United States would send a strong, unequivocal message that it opposes civil plutonium use worldwide. Furthermore, the DOE's preliminary technical and cost studies indicate that it will be faster, and probably cheaper, to immobilize plutonium surpluses than to irradiate them in reactors.[4]

After a brief review of the purpose of the disposition campaign and the technologies under consideration for the program, this essay rebuts the principal arguments offered in favor of using civil reactors. It then examines the negative economic and policy consequences of reactor use. Finally, it discusses the schedule, cost, and physical security advantages of the immobilization methods.

THE PURPOSE OF PLUTONIUM DISPOSITION

The United States has officially declared about 38 tons of plutonium surplus to its military needs, and is expected to declare another 14 tons surplus in the near future.[5] Russia possesses similar quantities of surplus plutonium.[6] All of this material is weapons-usable, and therefore at-

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tractive to terrorists, as well as to either country, should it choose once again to expand its nuclear arsenal. The United States and Russia have agreed that, in the long term, they cannot rely exclusively on their imperfect state security networks to protect military plutonium surpluses.[7] Instead, both countries plan to put the surplus material into a physical form that is difficult to steal, and from which it is significantly more difficult to extract plutonium.

Such a disposition program would accomplish four goals. First, the program would make it much harder for terrorists or subnational groups to steal military plutonium or to manufacture it into weapons. Second, it would increase the difficulty of reuse of the surplus material in weapons by either country. Third, it would provide a substantial nonproliferation benefit by sending a strong signal to the rest of the world that the major nuclear powers are at least on a path to irreversible reductions in their huge nuclear arsenals. Finally, it would aid progress towards further nuclear arms reductions by demonstrating that there are practical ways to reduce the array of threats associated with plutonium once it is removed from nuclear weapons.

While the accomplishment of these aims is of historic importance, the benefits of the disposition program should not be exaggerated. Because of current U.S. and Russian limitations on the amount of plutonium being declared surplus, both countries will still be able to reconstitute Cold War-sized arsenals quickly with their remaining, non-surplus plutonium stocks, even following the disposition campaign.[8] The ability to redeploy strategic nuclear weapons rapidly, in amounts well above existing treaty limits, will *not* be seriously affected by the campaign. Rather, the program is an important first step toward a more comprehensive campaign, involving progressively larger amounts of military plutonium that could eventually limit the current reversibility of arms reductions.

Despite misstatements made in press reports[9] and elsewhere,[10] the current disposition program also will not *destroy* strategically significant amounts of plutonium, regardless of which technology is used. The main physical effect that reactor irradiation and immobilization will have is to make military plutonium harder to recover and reuse.[11]

THE TECHNOLOGY FOR PLUTONIUM DISPOSITION

Following a major independent study of the subject by the National Academy of Sciences (NAS) in 1992,[12] the DOE began a comprehensive review of the technologies available for plutonium disposition. Broadly speaking, these divide into two classes: those that eliminate most or all of the plutonium and those that provide substantial physical barriers to its recovery.

According to both the NAS study and the DOE review, the elimination options, which included launching the material into the sun and fissioning it in advanced reactors or subcritical systems, were either too expensive, politically unfeasible, or too immature to be suitable for the plutonium disposition campaign.[13]

The barrier-type options included irradiation of plutonium in existing or partially built commercial reactors or immobilization with highly radioactive wastes.[14] These two technologies would have about the same physical result. Both would put the plutonium into a waste form (a spent reactor fuel assembly or a glass or ceramic log) that weighs several tons, has a height of around three meters, contains low plutonium concentrations (about one to 10 percent by weight), and emits lethal doses of radiation for one to several hundred years. This combination of properties makes the material about as difficult to recover as the plutonium contained in spent commercial reactor fuel. Both barrier-type options require similar preprocessing steps, which convert the plutonium into a form amenable to disposition.[15]

The NAS study also suggested that there is little security benefit in making military plutonium *less* accessible than the plutonium in civil spent fuel, because far more plutonium (by a factor of about four or five) exists in worldwide stockpiles of spent fuel than in military stocks.[16] This agreement on the level of reduction in threat from military stocks has come to be known as the “spent fuel standard.” It has been adopted as a guiding principle for the United States disposition program.

Overview Of the Immobilization Technologies

There are five immobilization technologies under consideration by the DOE.[17] These are:

1. **Direct Vitrification.** Plutonium and a neutron absorbing material such as gadolinium are mixed with molten glass and high-level radioactive waste, at concentrations of about five percent by weight, and cooled

into two-ton waste logs. This could be done either at the existing Savannah River high-level waste vitrification plant or at a new plant built specifically for the purpose.

2. Direct Ceramic Immobilization. Plutonium and a neutron-absorbing material are mixed in a ceramic material with high-level radioactive waste at concentrations of about 10 percent by weight. The resulting ceramic waste form is placed into a steel canister. This would be done at a newly built plant.

3. Can-in-Canister Vitrification. Plutonium and a neutron-absorbing material are mixed in glass without high-level waste in small steel cans. This process is followed by placement of the cans in three meter-long canisters, into which are poured molten, glassified, high-level radioactive waste that surrounds the cans and cools to provide physical and radioactive barriers to recovery.

4. Can-in-Canister Ceramic Immobilization. Plutonium and a neutron absorbing material are mixed with a ceramic material without high-level waste in small cans. As with can-in-canister vitrification, this is followed by covering the cans with molten glass mixed with high-level waste.

5. Electrometallurgical Treatment. Plutonium is mixed with radioactive waste into a monolithic mineral form called glass-bonded zeolite (GBZ).

The can-in-canister methods are the simplest immobilization technologies. Choosing an optimal glass or ceramic formulation is easier when plutonium is immobilized alone, rather than along with high-level waste. From a manufacturing standpoint, the can-in-canister methods may be easily integrated into the existing DOE radioactive waste treatment plant at the Savannah River Site. (Other methods will require major renovations to the site or construction of a new facility.) Because of their relative simplicity, the can-in-canister methods are estimated to have the shortest time to start-up, about seven years, and the shortest completion time, approximately 18 years, of all disposition options. The direct immobilization methods have start-up and completion times of about 12 and 21 years, respectively. The completion times are based on an assumed rate of plutonium immobilization ranging from 1.25 to five tons per year.[18]

Of the immobilization technologies, vitrification is the most mature. The United States has recently begun operation of a large scale plant to vitrify liquid high-level radioactive wastes at the Savannah River site in South Carolina. Other countries, such as Belgium, France, and the United Kingdom[19] have operated radioactive waste vitrification plants for a decade or longer. Thus, a large base of experience and knowledge exists for industrial-scale vitrification.

The plutonium content in vitrified high-level waste is small, typically less than one percent. Some research is required with higher plutonium concentrations to ensure long-term geologic stability. Plutonium oxide has been vitrified alone, without high-level wastes, at concentrations as high as 14 percent by weight.[20] The outstanding technical questions for the vitrification methods include the optimal level of solubility of the plutonium in glass, the optimal glass formulation, and the need to ensure that a critical mass of plutonium cannot accumulate in processing equipment. (Accumulation of a critical mass could lead to an explosion or release of radiation from the plant.)

The outstanding technical issues for ceramic immobilization are similar to those for vitrification. Ceramics hold the promise of enhanced stability over geologic times, as is pointed to by the existence of natural mineral deposits in which uranium and similar elements have remained immobilized for millions of years. However, less is known about ceramic immobilization on an industrial scale, since most countries with nuclear power and weapons programs have chosen vitrification as their preferred method of high-level waste disposal. The key step of incorporating plutonium in ceramics alone has been demonstrated on an engineering scale with samples containing greater than 10 percent plutonium by weight.[21]

Electrometallurgical treatment is less technically mature than the other disposition methods, having several key steps undemonstrated. The method is also expected to encounter stiff resistance due to its similarity to a form of reprocessing. It is, therefore, not discussed in detail here.

Overview Of the Reactor Options

The reactor methods would use existing reactors in the United States or Canada. Like the immobilization options, the reactor methods require that the plutonium be converted from metal and other physical forms into a plutonium oxide powder. Unlike those options, additional processing is needed to fabricate mixed-oxide (MOX) fuel from the plutonium oxide along with uranium oxide. Since no MOX production capacity exists in the

United States, a facility would have to be built. One partially built facility exists at the DOE's Hanford plutonium production site in Washington state.

Depending on the output of the MOX plant, the amount of fuel loaded, the plutonium fraction in the fuel, and the number of reactors employed, the DOE estimates that the reactor options would require approximately 25 to 30 years to implement.[22] This timetable assumes an acceleration of the schedule from two to four years, based on the use of European MOX facilities on an interim basis until a domestic facility is constructed.[23]

The reactors under consideration all have about one Gigawatt electric (GWe) power output[24] and can be loaded with up to 25 or 30 tons of MOX fuel per year, corresponding to 1.25 to 1.5 tons of plutonium per reactor per year (assuming five percent plutonium fraction in the fuel).

There is a wide base of experience using MOX fuel, primarily in French and German light water reactors.[25] Typically, 30 to 40 percent of the reactor core is loaded with MOX fuel, while the remainder is uranium-based fuel. To meet schedule requirements, the entire core of the reactors used for disposition would have to be loaded with MOX fuel ("full MOX core" operation). Preliminary analyses by U.S. industry state that, while there are no insuperable problems with such operation, there will be substantial increases in the difficulty of reactor safety controls and in the storage and management of spent MOX fuel.[26]

U.S. ARGUMENTS IN FAVOR OF THE REACTOR METHOD ARE INADEQUATE

In defending the decision to preserve the reactor option along with immobilization methods, Secretary O'Leary and other administration officials have put forth three main arguments.[27] First, that the use of two technologies provides greater flexibility in case of unforeseen problems with either; second, that the reactor methods provide an additional measure of proliferation resistance; and third, that the reactor option must be preserved to help the United States influence the Russian disposition program. The flaws in these lines of reasoning are discussed below.

The "Dual-Track" Argument

One of the main arguments made in favor of using *both* reactor and immobilization methods in the United States is that an alternative will remain in the event that one program is plagued by insoluble technical problems.[28] While this is certainly a desirable feature of the program, alternatives will remain even if the reactor option is abandoned in the United States. Major ongoing programs for the development of military plutonium use in reactors already exist in other industrialized countries, such as France, Germany, and Canada. From a technical standpoint, therefore, there is no need for a redundant program in the United States. Moreover, if technical flexibility is desired, the United States can pursue both vitrification and ceramic immobilization methods simultaneously. As indicated above, these are also two distinct technologies. Like reactor irradiation, both of these immobilization methods have made the final cut in the DOE's search for viable ways to disposition plutonium. However, neither raises nonproliferation concerns; those problems are unique to the reactor method.

The "Isotopic" Argument

A second argument frequently put forth in favor of the reactor method relates to the change in isotopic composition that takes place when military plutonium is irradiated in a reactor.[29] The resulting plutonium, termed "reactor-grade" has a higher rate of spontaneous fission and heat production than the original "weapons-grade" military plutonium. These factors make designing a nuclear explosive with it more difficult. The isotopic change is often cited as an advantage to the reactor method, since no such degradation occurs in the immobilization methods. In fact, the change is largely irrelevant from a nonproliferation standpoint. While it is true that the altered composition somewhat complicates bomb design, it is equally true that a terrorist or a nuclear weapons state could still make a bomb thousands of times more powerful than a conventional weapon using the degraded plutonium. The isotopic composition of the material, therefore, has little effect on its security risk. For this reason, the authoritative study of plutonium disposition by the NAS stated: "Theft of separated plutonium, *whether weapons-grade or reactor-grade*, is a major security risk" (italics added).[30]

Reactor-grade plutonium offers no important arms control advantage; moreover, it is dangerous to perpetuate the myth that the isotopically altered plutonium in civil spent fuel is somehow significantly less of a security problem.[31] This point becomes particularly relevant when analyzing Russian attitudes towards disposition.

The Russian Argument

Because Russian plutonium stocks are far more vulnerable than those of the United States, the full security and nonproliferation benefits of the United States' plutonium disposition program can only be realized if a similar campaign proceeds in Russia. Therefore, close attention must be paid to Russian opinions and actions concerning disposition.

Due in part to a powerful domestic lobby for nuclear energy, and a widespread, if mistaken, perception that use of military plutonium stocks may help solve Russia's energy problems, the Russian government is insisting on the use of reactors for their military disposition program. In addition, Russia's research in immobilization is poorly developed, and the scientific establishment has little enthusiasm for the technology.[32] More importantly, Russian government officials responsible for nuclear energy policy view the disposition program as a precursor to a plutonium recycling fuel cycle.[33]

American proponents of the reactor method use the Russian position to justify the dual-track policy. They maintain that the United States must also pursue reactor methods, arguing that it will be easier both to monitor and to ensure Russian participation if the United States uses an identical technology.[34] These arguments have little validity, and ignore what is perhaps the United States' strongest bargaining chip and Russia's greatest interest: the considerable amount of funding that the United States will have to provide to the Russian Ministry of Atomic Energy (Minatom), the agency that oversees disposition in Russia, to ensure timely completion of the campaign there.

As far as ensuring Russian participation is concerned, it is important to recognize that Russia has not made its disposition campaign contingent on U.S. use of reactors. In fact, the only bilateral study reflecting Russian attitudes made available by the DOE, *The Joint United States/Russian Plutonium Disposition Study*, concluded that:

> The United States and Russian need not use the same disposition technology. Indeed, given the very different economic circumstances, nuclear infrastructures, and fuel cycle policies in the two countries, it is likely that the best approaches will be different in the two countries.[35]

The co-chairman of that study, Nikolai Yegorov, deputy minister for the fuel cycle at Minatom, heads the Russian plutonium disposition effort. If the Russian officials responsible for disposition do not object to U.S. pursuit of immobilization, it seems unnecessary for the United States to anticipate objections by preserving the reactor option.

Although reactor use in the United States may not be required to *ensure* Russian participation, the argument that identical technologies will aid in *monitoring* the Russian disposition program is a stronger one. For example, if both countries use reactors, identical verification measures could be employed to help guarantee that neither country is diverting plutonium from the disposition program. However, while this is an advantage, it is not much of one. The verification measures for immobilization are technically similar to those used in the reactor method. In fact, perhaps the most sensitive and difficult element of the verification procedure from both Russian and U.S. security standpoints—ensuring that classified metallic plutonium pits are converted to the unclassified plutonium oxide form for further processing—is identical for the reactor and immobilization methods. Furthermore, although there is more experience in detecting plutonium diversion in MOX plants than in vitrification facilities, it may well prove technically easier to detect diversion in the latter plants.[36] Indeed, this relative ease might be an inducement to Russian participation. On balance, the small advantage gained for the verification regime by using identical technologies is far outweighed by the major risks associated with plutonium use in U.S. civil reactors.

Instead of compromising with Russia on a point it has yet to take a firm stand on, the United States should seek definite commitments from the Russians using its strongest bargaining tool—money. Russia's insistence on using reactors in the disposition program is driven, at least in part, by the uncertain future and difficult economic straits of the Russian weapons complex, which will oversee disposition. The weapons laboratories (and their directorate Minatom) have yet to find a new mandate or new funding sources. They are looking to the United States to provide both through aid to the Russian program. If the United States does agree to such funding, it should ask for strong assurances about the campaign in exchange. For example, the United States should demand that no new plutonium be separated from spent fuel while disposition takes place, and that the United States be allowed to help build pilot vitrification plants in Russia. Because of the powerful economic incentives the United States can offer, it need not jeopardize its long-held policy of shunning a domestic plutonium fuel cycle to ensure Russian involvement.

A final rationale given for the use of identical technologies is the possible Russian objection to the discrepancy in isotopic composition between immobilized and reactor-irradiated plutonium. Because no nuclear weapons program in history has relied on reactor-grade plutonium and because of the likely entry into force of the Comprehensive Test Ban Treaty, the Russians may object to the fact that U.S. plutonium remains in the well understood (and well tested) weapons-grade form, while theirs is converted to reactor-grade. Using reactors in the U.S. program would certainly avoid this problem.

However, there is another, better way of accomplishing the same goal without using reactors. If Russia were to refuse to participate in a disposition program that did not involve a change in the isotopic composition of U.S. plutonium (something it has yet to do) the United States could still immobilize its plutonium. To provide the isotopic barrier, the United States could simply mix its stocks of surplus weapons-grade plutonium with its surplus reactor-grade plutonium[37] prior to immobilization. The mixing process could take place once both types of plutonium are converted to nitrate form, which is a pre-processing step for some immobilization methods. (Such isotopic blending down is also possible with plutonium oxide, although this is probably less preferable from the standpoint of worker safety.) Isotopic blending of plutonium nitrate is a straightforward, well understood technology: the United States used it over the course of several years in the 1980s to blend so-called "super-grade" and "fuel-grade" plutonium stocks to form weapons-grade plutonium.[38] Enough non-weapons-grade plutonium exists in the U.S. stockpile to allow for isotopic degradation of about half the declared U.S. surplus of weapons-grade plutonium—and it is conceivable that additional amounts of reactor-grade plutonium could be purchased from the Russians, who have about 30 tons of separated reactor-grade plutonium. This process could add some expense, and possibly some delay to the U.S. disposition program. Nonetheless, it is certainly worth investigating before the United States risks the economic and political endorsement of plutonium use in civil reactors.

Because the United States does not consider the difference in threat between reactor-grade and weapons-grade plutonium significant, the intrinsic security value of isotopic blending is essentially nil. The blending technology merely allows the United States to meet any Russian demands for parity in isotopic composition without using reactors in its own disposition program.

REACTORS SHOULD NOT BE USED TO DISPOSITION PLUTONIUM

Having examined and rebutted the arguments put forth in favor of pursuing the reactor option in the United States, let us now turn to an even more important nonproliferation issue: the harmful effects the military reactor disposition program would have on domestic and international nuclear fuel cycles.

Negative Effect On Civil Plutonium Use in the United States

Pursuit of the reactor method for plutonium disposition by the United States will adversely affect the domestic nuclear fuel cycle. The program requires the construction of a large industrial facility to manufacture plutonium-based MOX reactor fuel. Once the disposition campaign is complete, the fuel manufacturing plant will still have a useful remaining lifetime of about 15 to 25 years. This fact will be a powerful impetus to continue manufacturing MOX fuel, either for sale abroad or for use in U.S. reactors. If the plant is simply shut down following the campaign, as nonproliferation policy would demand, much of the huge capital investment made by the government will have been wasted.

If the disposition in the United States does proceed with reactors, an essential element of the plutonium fuel cycle will remain unbuilt. To complete the cycle, a reprocessing plant, used to recover plutonium from spent fuel, would have to be constructed. The cost of building a reprocessing plant is significantly greater than the cost of constructing a MOX plant.[39] This high cost, in conjunction with the relatively low cost of ordinary reactor fuel, is considered to be a principal obstacle to the institution of a plutonium fuel cycle in the United States for the next several decades.[40] Because this economic obstacle would remain even if a MOX plant were constructed, some analysts have argued that the disposition program will not have a major effect on the U.S. nuclear fuel cycle.[41] This is incorrect for two reasons. First, strong economic incentives to use the MOX fabrication plant will be present even without the construction of a reprocessing plant. For example, following the disposition campaign, the owner of the MOX plant could secure fuel fabrication contracts with European countries or Japan, which may well require these services in the future for their separated plutonium. Because the capital cost of the MOX plant (roughly one-half of its total cost) will already have been paid for during the disposition campaign, the plant owner might be able to offer competitive prices for plutonium fuel fabrication once the campaign is finished. Second, experience in other countries over the past two decades has shown that even when plutonium recycle has proven uneconomical, the large sunk costs of nuclear facilities have frequently been used as one argument to justify further government spending. This has been the case in both France and Britain, for example.

In addition to a likely direct economic subsidy, there are regulatory and political "subsidies" for civil plutonium use if the reactor method is chosen. It will be much easier to license reactors and fuel fabrication plants for plutonium use once regulatory approval for those types of facilities has been sought and received by the disposition campaign. Politically, the expensive, high-profile program will provide a major infusion of resources and prestige to the otherwise moribund nuclear industry.

On the other hand, local opposition to use of plutonium in reactors is likely to be strong. Even ordinary nuclear reactors, using uranium-based fuel, encounter strong local resistance in the United States in the form of lawsuits and protests. The controversy attending the use of plutonium in domestic reactors could be greater still, and could slow down the all-important task of dispositioning military plutonium stocks. Public opposition to immobilization methods is less likely because these are expected to be performed at existing sites previously used in the weapons program, at which huge amounts of plutonium have already been produced and processed.

Negative Impact On Civil Plutonium Use Abroad

Internationally, strong U.S. opposition to civil plutonium use would be weakened by domestic use of plutonium for energy production. This would make it more difficult to persuade other countries, including Russia, Canada, Japan, and France, to move away from plutonium use in reactors. John Holum, director of the U.S. Arms Control and Disarmament Agency, has written that other countries "would hear only one message for the next 25 years: that plutonium use for generating commercial power is now being blessed by the United States."[42]

Recognizing this possibility, the Clinton administration has argued that it could mitigate the "blessing" by pledging that facilities would only be used to render military plutonium stocks less accessible, and by expressly forbidding any subsequent civil use of the MOX plant and reactors.[43] However, such pledges are of dubious value—indeed they are probably of no value at all. They cannot be verified by other countries for several decades, so they are unlikely to inspire much international confidence. Furthermore, any pledges made now will certainly have to be reaffirmed by policymakers 25 years in the future, once the disposition campaign is complete. Considering that U.S. plutonium use policy has been reversed several times since the Nixon era,[44] it is hard to imagine that present-day guarantees will be worth much in 30 years.

SUMMARY OF ADVANTAGES OF THE IMMOBILIZATION METHODS

Besides their clear superiority from a global nonproliferation perspective, immobilization options offer additional several benefits. These include likely advantages in timing, cost, and in keeping the process secure during the implementation phase. None of these latter considerations is in itself decisive, but taken together, they clearly favor immobilization.

Speed

A key factor for choosing among options is the relative speed of completion. Preliminary analyses by the DOE[45] show a definite schedule advantage to immobilization methods—particularly the can-in-canister methods. The latter could be completed as many as five to 13 years sooner than reactor disposition methods. Moreover, the DOE timing estimates for the reactor methods assume that European MOX facilities will be made available for the program while a U.S. MOX fabrication plant is built. Actually achieving an early start in this case seems doubtful, however, since the nominal time advantage gained from the use of European facilities will probably be erased by the public opposition and security problems associated with large-scale transportation of plutonium overseas. If European MOX plants are not used, as they should not be, the schedule advantage to the immobilization methods is greater still.

Cost

Compared to the huge costs associated with obtaining nuclear materials, the cost of a disposition campaign is low—particularly in light of the great nonproliferation and security benefits of the program. Therefore, cost should not be a deciding factor in choosing an option. It does play a role in a practical sense, however, since timely Congressional and public approvals depend to an extent on keeping the costs of the program down. Delay due to high costs, or large uncertainties in cost, will adversely affect the program and lessen its benefits. In this sense, the immobilization methods enjoy a definite advantage.

There are many factors contributing to the uncertainty in DOE estimates for the reactor options that are absent for the immobilization methods. For example, the DOE considers incentive fees paid to utilities to represent a major cost uncertainty for the reactor methods, yet it did not estimate these fees. In addition, utilities have recently warned the DOE to expect higher operating costs due to the increased difficulty of using and storing MOX fuel, which has a higher in-core neutron production rate and a higher heat output than ordinary reactor fuel. The utilities have further claimed that the DOE's assumptions concerning the length of time MOX fuel assemblies remain in the reactor are unrealistic, concluding that a more realistic analysis: "...would substantially increase the length and cost of (the DOE's) program to dispose of surplus plutonium in commercial reactors."[46] Immobilization methods will avoid these large cost uncertainties and, therefore, can probably be more quickly approved and completed.

Security During the Execution Phase

Yet another advantage of the immobilization methods is that transportation and physical security during the disposition campaign can be somewhat simplified because all plutonium processing facilities can be located at a single site. For the reactor method, the use of multiple sites is unavoidable.

CONCLUSION

The above analysis has sought to contribute two main points to the on-going debate on U.S. plutonium disposition options. First, that the proponents of the reactor options have not demonstrated that there is any real need to use such methods in the U.S. disposition program, and, second, that the great damage to U.S. nonproliferation interests caused by using reactors for disposition ought to lead the Clinton administration to look elsewhere for safer, more proliferation-resistant methods.

If there were no other way of accomplishing the essential goal of rendering military plutonium surpluses safe from theft and reuse, the formidable security and nonproliferation risks associated with keeping the reactor option open in the United States could perhaps be justified. Fortunately, though, there *are* other technical possibilities to choose from. Ceramic- and glass-based immobilization are sufficiently distinct to count as alternative technologies. If the United States wishes to preserve flexibility in its disposition program, and send a strong signal of its opposition to plutonium use globally, it can and should vigorously pursue both immobilization technologies. This approach is far preferable to taking the manifestly dangerous step of introducing elements of a plutonium fuel cycle into the U.S. economy.

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[1] Separated weapons-usable plutonium in civil fuel cycles is projected to exceed the amount in the world's military stockpiles by the turn of the century. ~~David Albright, Frans Berkhout, William Walker, *World Inventory of*~~ *Plutonium and Highly Enriched Uranium, 1992* (Stockholm: Stockholm International Peace Research Institute, 1993), Table 12.1, p. 197, and Table 12.8, p. 205.

[2] The White House, Press Release, September 27, 1993, "Nonproliferation and Export Control Policy."

[3] Department of Energy (DOE), Press Release, December 9, 1996, "Energy Secretary Unveils Strategies to Reduce Global Nuclear Danger." The press release states that "...the department, over the next two years, will complete the necessary tests, process development, technology demonstrations, site-specific environmental reviews and detailed cost proposals for both approaches. Final decisions to use either or both of these technologies depend on the results of this work as well as nonproliferation considerations and progress in efforts and negotiations with Russia and other nations."

[4] DOE, Office of Fissile Material Disposition (OFMD), *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition*, DOE/MD-0003, Rev. 1 (Washington, D.C.: DOE, OFMD, November 1996), Table ES-2, p. ES-11, and Figure ES-2a, p. ES-8.

[5] *Ibid*., p. ES-1. The United States surplus stockpile includes about 20 tons of plutonium in the form of three to five kilogram metal "pits," taken directly from dismantled weapons, and currently in storage at the Pantex dismantlement and storage facility in Texas. The remainder of the U.S. surplus is in the form of plutonium dioxide, scraps, and other residues and is located at several DOE sites, with the largest amount (about 12 tons) at the Rocky Flats Environmental Technology Site in Colorado.

[6] National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium* (Washington, D.C.: National Academy Press, 1994), p. 1.

[7] This problem is much more acute in Russia, where the tight security network surrounding the weapons complex has largely unraveled since the end of the Cold War. But the United States, too, may have difficulty maintaining the physical security of its fissile materials in the long term. For more information on the status of Russian plutonium, see Frank Von Hippel, "Fissile Material Security in a Post-Cold-War World," *Physics Today* (June 1995), p. 26-31.

[8] For more information on the size of the arsenal the United States will be able to redeploy or rebuild quickly following the diposition campaign, see Adam Bernstein and Lisbeth Gronlund, "Comments By the Union Of Concerned Scientists on the Draft Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Plutonium Disposition Alternatives," Union of Concerned Scientists, Cambridge, MA, November 8, 1996.

[9] Thomas Lippmann, "U.S. Decides on Plutonium Disposal Plan," *The Washington Post,* December 9, 1996, p. A-1. The article repeatedly refers to military plutonium stockpiles being "destroyed."

[10] Charles N. Van Doren, "Getting to Burn Weapons Plutonium: Principal Issues and Obstacles," *The Nonproliferation Review* 4 (Fall 1996), p. 98. Van Doren's article, referring to nuclear reactor performance, states that " A substantial fraction of this plutonium is consumed ('burned') during such operations" (p. 98). The incorrect implication is that significant amounts of plutonium are being destroyed by the reactor disposition program. While some plutonium is fissioned during reactor irradiation, new plutonium is produced by neutron capture in uranium nuclei. The exact ratio depends on the plutonium concentration in the fuel and the length of exposure or "burnup" in the reactor. Typically, only about 20 to 60 percent of the plutonium is fissioned. Taking as exemplary Van Doren's own figure of 60 kilograms of plutonium fissioned per Twh, and assuming about 240 Twh are needed to disposition 50 tons of plutonium, only about 30 percent of the initial 50 ton plutonium stock would be fissioned. The disposition campaign will not destroy strategically significant quantities of plutonium. (The estimate of 240 Twh of energy production is derived by assuming five one Gwe reactors using one ton of plutonium each per year, operating 24 hours per day, 200 days per year for 10 years.)

[11] It is possible in principle to use advanced reactors or accelerator/reactor combinations to destroy large amounts of plutonium over periods of decades. However, such technologies are too expensive and technically immature to make them useful for the current disposition program.

[12] National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium*.

[13] DOE, OFMD, *Storage and Disposition of Weapons-Usable Fissile Materials Draft Programmatic Environmental Impact Statement, Volume I (*Washington, D.C.: DOE, OFMD, February 1996), p. 2-14.

[14] Another option, burial in deep boreholes, was also proposed in the NAS study and investigated by the DOE. Although considered technically feasible, it was ultimately rejected because of the strong likelihood of legal challenge and political resistance to the choice and licensing of a burial site.

[15] Plutonium stocks must be converted from metallic and other forms into either a plutonium dioxide powder or a plutonium nitrate solution to allow further processing. Reactor fuel fabrication requires the oxide form and places strict tolerances on the plutonium dioxide particle size and purity. Immobilization methods can accept either nitrate or dioxide forms, and the tolerances on purity and particle size are looser. Preprocessing will be performed at the same site were fuel fabrication or immobilization occurs to minimize transportation of the plutonium.

[16] A chart comparing military and civil plutonium stocks may be found on the World Wide Web at the NCI web page (http://www.nci.org:80/nci/images/nptcht2.jpg). The data there are adapted from David Albright, Frans Berkhout, and William Walker, *World Inventory of Plutonium and Highly Enriched Uranium, 1992 (*Stockholm: Stockholm International Peace Research Institute (SIPRI), 1993), Table 12.1, p. 197, and Table 12.8, p.205.

[17] DOE, OFMD, *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition*, p. ES-3.

[18] *Ibid.*, Table ES-2, p. ES-11.

[19] "Fuel Cycle Facilities in Europe" (www.uilondon.org/ bendtab.html).

[20] George Wick, Senior Researcher, Savannah River Site, Aiken, South Carolina, telephone conversation with the author, January 15, 1997.

[21] Lawrence Livermore National Laboratory, *Fissile Materials Disposition Program, Alternative Technical Summary Report: Ceramic Can-in-Canister Variant*, UCRL-ID-122661,L-20219-1 (Livermore, California: Lawrence Livermore National Laboratory, August 26,1996), p.1-1.

[22] DOE, OFMD, *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition,* Table ES-2, p. ES-11.

[23] *Ibid*.

[24] DOE, Energy Information Administration, *World Nuclear Capacity and Fuel Cycle Requirements 1993*, DOE/EIA-0436/93 (Washington, D.C.: U.S. Government Printing Office, November 1993), Appendix D, p. 103-107.

[25] "MOX Industry Worldwide," in Yurika Ayukawa, ed., "Fissile Material Dispositon & Civil Use Of Plutonium," Issue No. 2, October 3, 1996 (www.cdi.org/~nukenerd/issues/fm/yurifis2.html#moxutil).

[26] George Lobsenz, "ComEd Raises Spent Fuel Questions On DOE Plutonium Disposal Plan," *The Energy Daily*, December 12, 1996, p. 1.

[27] Peter Passell, "U.S. Set to Let Reactors Use Bomb Plutonium," *The New York Times,* November 22, 1996, p. A3.

[28] Thomas Lippman, "U.S. Decides on Plutonium Disposal Plan."

[29] Peter Passell, "U.S. Set to Let Reactors Use Bomb Plutonium."

[30] National Academy of Sciences, *Management and Disposition of Excess Weapons Plutonium,* p. 33.

[31] Surprisingly, even some members of the authoritative Secretary of Energy Advisory Board Task Force have stated that "...converting the excess weapons plutonium to reactor-grade would offer an additional contribution to the international perception of the irreversibility of U.S. plutonium disposition." DOE, Office of Arms Control and Nonproliferation, *Draft Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Plutonium Disposition Alternatives* (Washington, D.C.: Office of Nonproliferation and Arms Control, October 1, 1996), Appendix B, p. 144. Even if such a perception did exist *(*itself a questionable assumption) it would be both unfounded and inimical to U.S. nonproliferation and security goals, since it implies a belief that there is some important difference in the security risks of weapons-grade and reactor-grade plutonium.

[32] Anatoly Diakov, "Utilization of Already Separated Plutonium in Russia, Consideration of Short and Long Term Problems," Moscow Institute of Physics and Technology (unpublished paper), 1995, p. 5.

[33] *Ibid*., p. 3.

[34] Peter Passell, "U.S. Set to Let Reactors Use Bomb Plutonium."

[35] DOE, OFMD, "Joint United States/Russian Plutonium Disposition Study," (Washington, D.C.: DOE, OFMD, September 1996), p. ExSum-2.

[36] This is probably the case for can-in-canister methods, which have fewer processing steps than the reactor options, and which allow for simple accountancy of items with fixed plutonium content as soon as the plutonium has been placed in small cans. Further discussion of the difference in safeguarding technologies for immobilization and reactor methods is found in Adam Bernstein and Lisbeth Gronlund, "Comments By the Union Of Concerned Scientists on the Draft Nonproliferation and Arms Control Assessment...."

[37] According to the DOE *Technical Summary Report*, the U.S. surplus by the time disposition commences will include 15 tons of less-than-weapons-grade plutonium. DOE, OFMD, *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition,* p. ES-1.

[38] Roger Heusser, DOE, Office of Nonproliferation and National Security, telephone conversation with the author, December 23, 1996.

[39] The extra expense derives primarily from the fact that the entire plutonium recovery process must be accomplished with robotic or remote-handling equipment, due to the high levels of radioactivity that emanate from spent reactor fuel.

Estimates of the cost of large-scale reprocessing plants vary widely. A figure of $2.8 million (1992 dollars) for the capital cost of the THORP reprocessing plant, with an output of about five tons of plutonium per year, is found in Brian Chow, *Limiting the Spread of Weapons-Usable Fissile Materials (*Santa Monica, CA: RAND, 1994), p. 23. A higher figure of $16.3 billion dollars for the Rokkasho plant in Japan, with similar rate of plutonium output, is found in Paul Leventhal and Steve Dolley, *A Japanese Strategic Uranium Reserve: A Safe and Economic Alternative to Plutonium (*Washington, D.C.:, Nuclear Control Institute, January 14, 1994), p. 23.

[40] Brian Chow, *Limiting the Spread of Weapons-Usable Fissile Materials*, p. 35.

[41] Van Doren, "Getting to Burn Weapons Plutonium: Principal Issues and Obstacles," p. 100.

[42] Dave Airozo, "Nonproliferation Concerns Muddle Clinton Administration Policy," *Nuclear Fuel*, December 2, 1996, p. 8.

[43] DOE, Office of Arms Control and Nonproliferation, *Draft Nonproliferation and Arms Control Assessment of Weapons-Usable Fissile Material Storage and Plutonium Disposition Alternatives*, p. 90.

[44] For example, from 1966 to 1972, the government subsidized a small-scale commercial spent fuel reprocessing plant in West Valley, New York. (Now, 25 years later, the DOE is spending about $1 billion vitrifying liquid high-level wastes at that site.) As a second example of the policy change, following President Carter's injunction against reprocessing and plutonium use, Ronald Reagan made an official statement early in his first term encouraging domestic use of plutonium.

[45] DOE, OFMD, *Technical Summary Report for Surplus Weapons-Usable Plutonium Disposition*, Table ES-2, p. ES-11.

[46] George Lobsenz, "ComEd Raises Spent Fuel Questions On DOE Plutonium Disposal Plan," *The Energy Daily*, December 12, 1996, p. 1.